

Europe-LAND Webinar #14: Future expected land-use patterns in the EU
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Modelling agricultural and forest land dynamics in Romania under near-future climate scenarios

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Climate change directly influences agricultural and forest systems by altering productivity, water availability, distribution and health (IPCC, 2019; 2022)

Several studies have identified a strong correlation between climate drivers and LULC patterns (e.g., Münch et al., 2019; Zewdu et al., 2025), mainly affecting agriculture and forestry (e.g., Beach et al., 2015; Arora et al., 2020)

understanding the future dynamics of agriculture and forestry under climate change scenarios at different scales is highly necessary to properly design sustainable land management strategies

LULC is a dynamic and complex phenomenon caused by the interactions of different natural and socioeconomic factors

This modelling aims to identify areas potentially exposed to future climatic pressures and changes in land suitability, with a focus on agricultural and forest systems

The Context (Europe-LAND Project)



Two BASELINE SCENARIOS (BS)

BS1 = scenario that simulated future LU/LC pattern change under the current condition of driving factors, and current LU/LC changes. The future demand is adapted to current trend of LU/LC pattern change, registered in the post-communist period (>1990)

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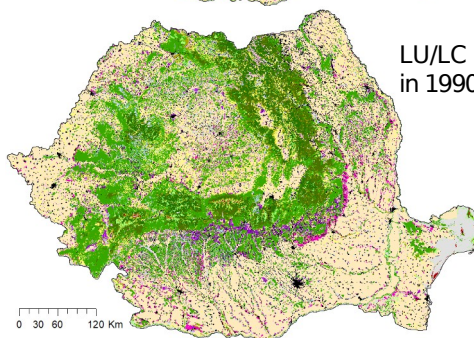
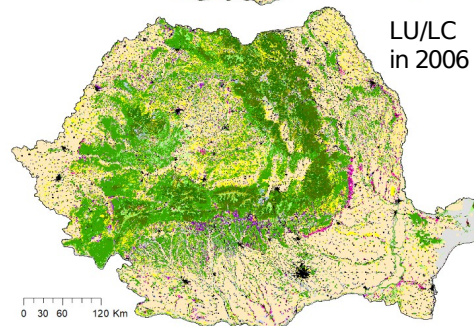
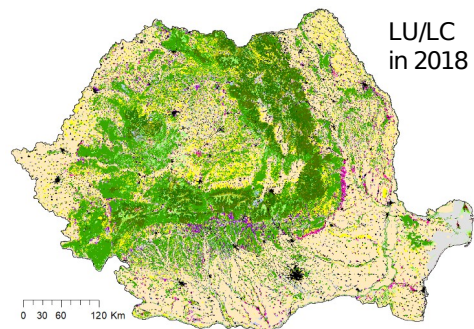
Four ALTERNATIVE SCENARIOS

Sbc = scenario that simulated future LU/LC pattern change taking into account LU/LC conservation strategies inside the protected areas

Scc = scenarios that simulated future LU/LC pattern change under the climate change:

- 1) According to **SSP1-2.6**
- 2) According to **SSP3-7.0**
- 3) According to **SSP5-8.5**

LU/LC classes	Code	Main category
Built-up areas	0	ARTIFICIAL AREAS
Arable lands	1	AGRICULTURAL AREAS
Vineyards	2	
Orchards	3	
Agricultural complex cultivation patterns	4	
Heterogenous Agricultural areas	5	
Pastures	6	SEMI-NATURAL/NATURAL AREAS
Natural grasslands	7	
Transitional woodland-shrub	8	
Broad-leaved forest	9	
Mixed forest	10	
Coniferous forest	11	LUC RESTRICTED WITH COMPLEX DYNAMICS
Open spaces with little or no vegetation	12	
Not simulated	13	



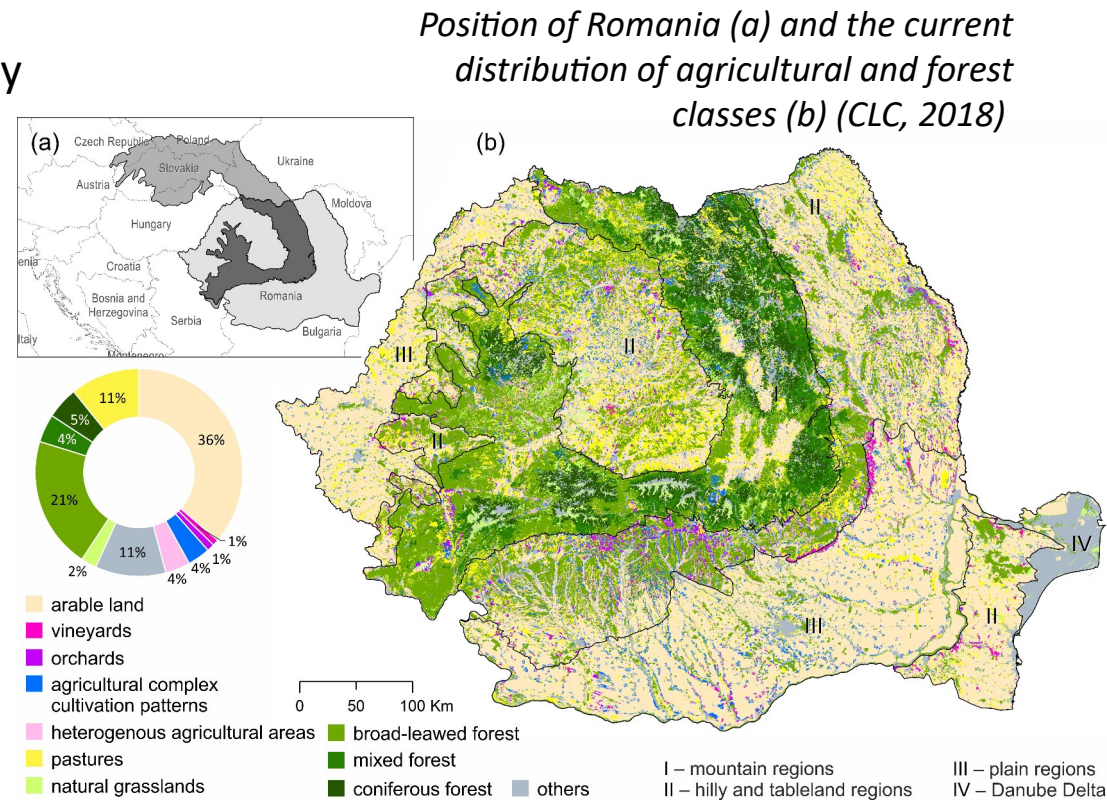
Past LU/LC pattern change (1990-2018; **2006-2018**)

Linear trend of LU/LC pattern change (2019-2050)

The study area: Romania

- a South-Eastern European country
- covering around 238,400 Km²
- high diversity of landscapes
- includes 42% of the Carpathian Mountains

A relevant case study for examining the spatial response of agricultural and forest systems to changing climatic conditions



Agricultural land = 53% of the country's total area (12,689,000 ha) = (8.1% of EU; Eurostat, 2024; <https://ec.europa.eu/eurostat/databrowser/view/tag00025/default/table?lang=en>)

Afforested land = 29% of the country's total area (6,957,000 ha) = (3.5% of EU; Eurostat, 2025; https://ec.europa.eu/eurostat/databrowser/view/for_area/default/table?lang=en&category=for.for_sf)

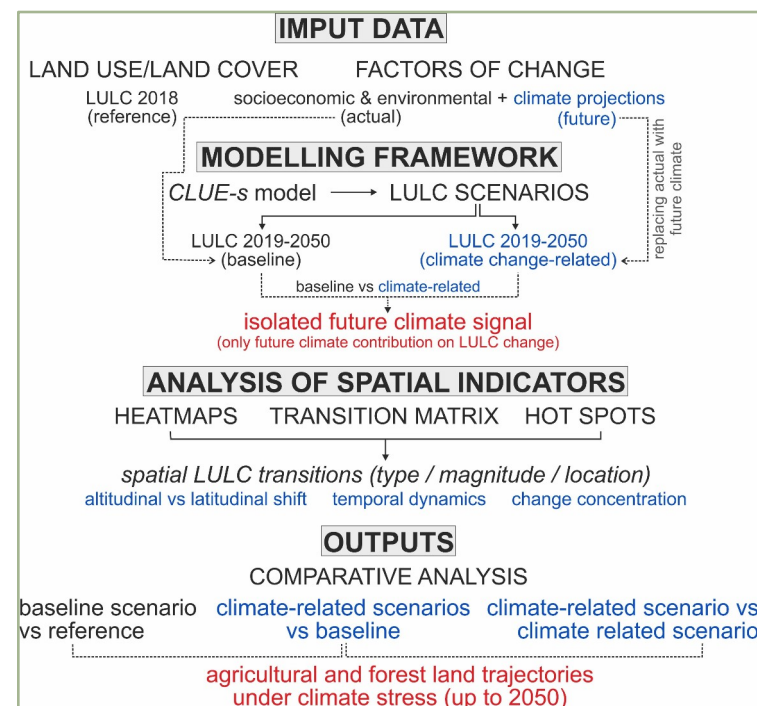
Methods & datasets



- **Pattern-based simulation method (CLUE-S model)**
- **CLC database (2006, 2018) & 20 Factors of change:** environmental, socioeconomic, distance factors, protective measures
- **3 climate projections** (aligned with the Shared Socioeconomic Pathways): SSP1–2.6; SSP3–7.0; SSP5–8.5 (growing-season mean temperature and precipitation)
- **Simulation period:** 2019–2050
- **Simulation resolution:** 250 m
- **13 LULC categories simulated:** *Built-up areas; Arable lands; Vineyards; Orchards; Agricultural complex cultivation patterns; Heterogenous Agricultural areas; Pastures; Natural grasslands; Transitional woodland-shrub; Broad-leaved forest; Mixed forest; Coniferous forest; Open spaces with little or no vegetation*
- **4 scenarios:** Baseline (BS) & 3 climate change-related (CCSs)

Other procedures:

- *SHapley Additive Explanations – SAHP* (contribution of current climate)
- *the non-parametric Mann–Kendall test* (= spatial trend)
- *bidimensional heatmaps* (= spatial shift)
- *transition matrix* (= structural dynamics)
- *Cells exceeding the 90th percentile* (= hotspots)



Working hypothesis: assuming that changes in thermal and pluvial regimes will lead to shifts in the spatial distribution of agricultural and forest lands, while non-climatic drivers remain unchanged



changes in agricultural and forest lands are quantified exclusively as potential responses to the modelled climatic variation



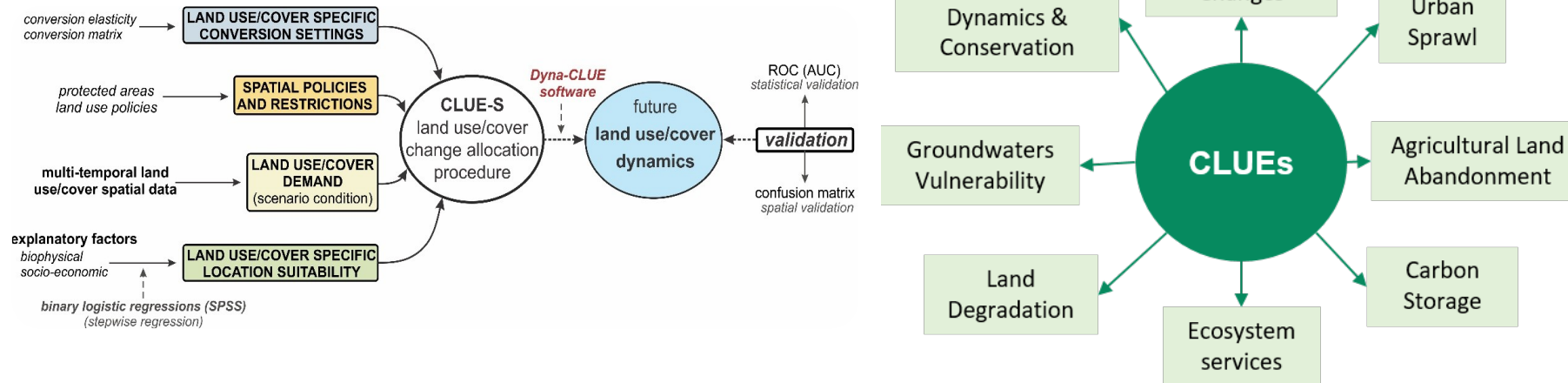
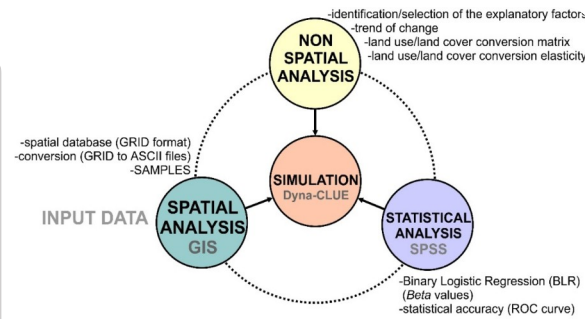
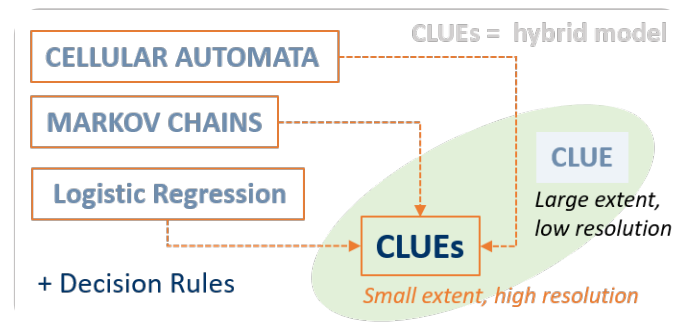
understanding climate contribution on agricultural and forest lands

Methods & datasets



CLUE-S = a model specifically developed for the spatially explicit simulation of LU/LC pattern change, based on an empirical analysis of location suitability combined with the dynamic simulation of the competition and interactions between the spatio-temporal dynamics of LU/LC systems (Veldkamp and Fresco, 1996, Verburg et al., 1999; 2004; 2010)

Pattern-Based Scenarios of Potential Agricultural and Forest Land Dynamics Integrating Climate Scenarios in **CLUE-S** (the Conversion of Land Use and its Effects at Small regional extent) model (Verburg and Overmars, 2009)



Where will the LU/LC pattern change take place? (= location)

What LU/LC pattern change will occur? (= transition/conversion)

When will the LU/LC pattern change take place? (= time)

How much will it change? (= magnitude)

Results

Climatic influence on agricultural and forest dynamics The projected evolution of climate indicators



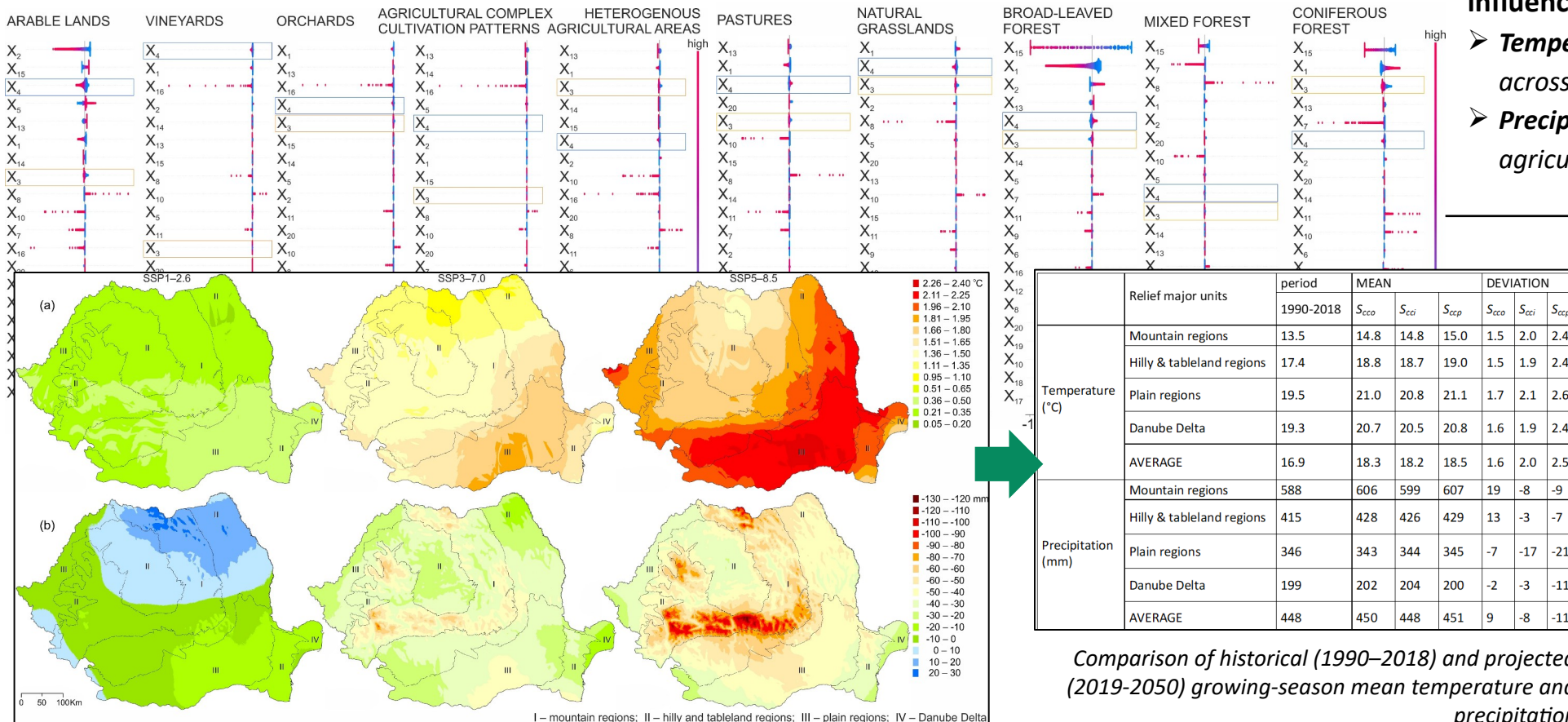
SHAP: Relative importance and direction of influence

- **Temperature** = more consistent contribution across the analysed LULC
- **Precipitation** = particularly relevant for several agricultural classes



Overall moderate changes

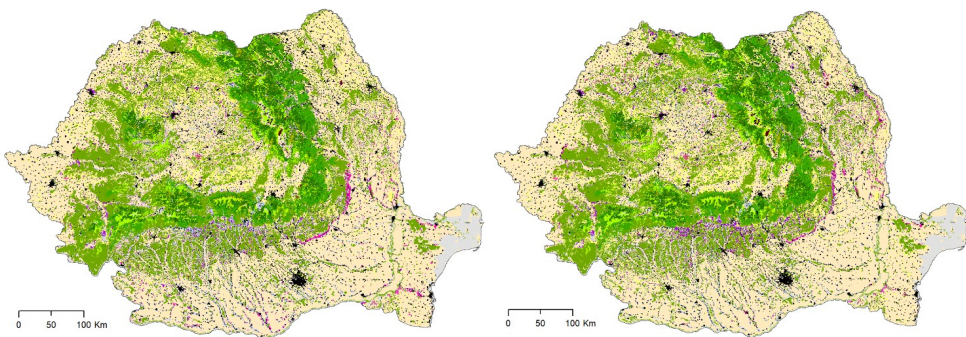
- significant increases in **temperature** for all projections, with averages rising from 1.6 to 2.5 °C, particularly in plain and mountain regions
- **Precipitation** shows slight decreases across plain regions and the Danube Delta, while mixed trends are observed in mountain, hilly, and tableland regions



Comparison of historical (1990–2018) and projected (2019–2050) growing-season mean temperature and precipitation

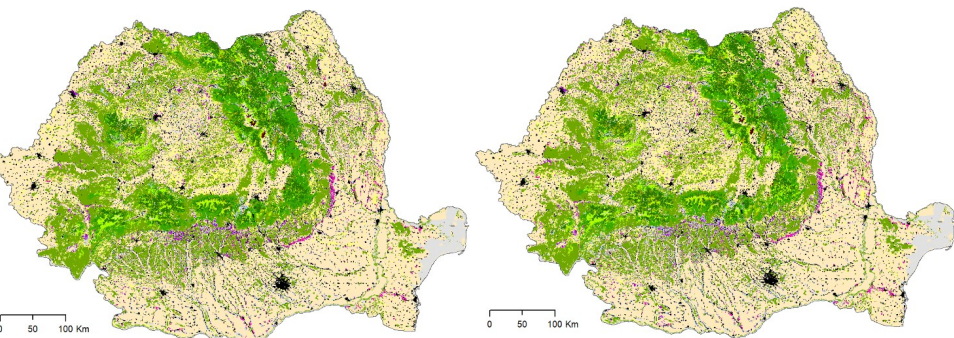
Results

Projected LULC pattern in 2050 under climate change



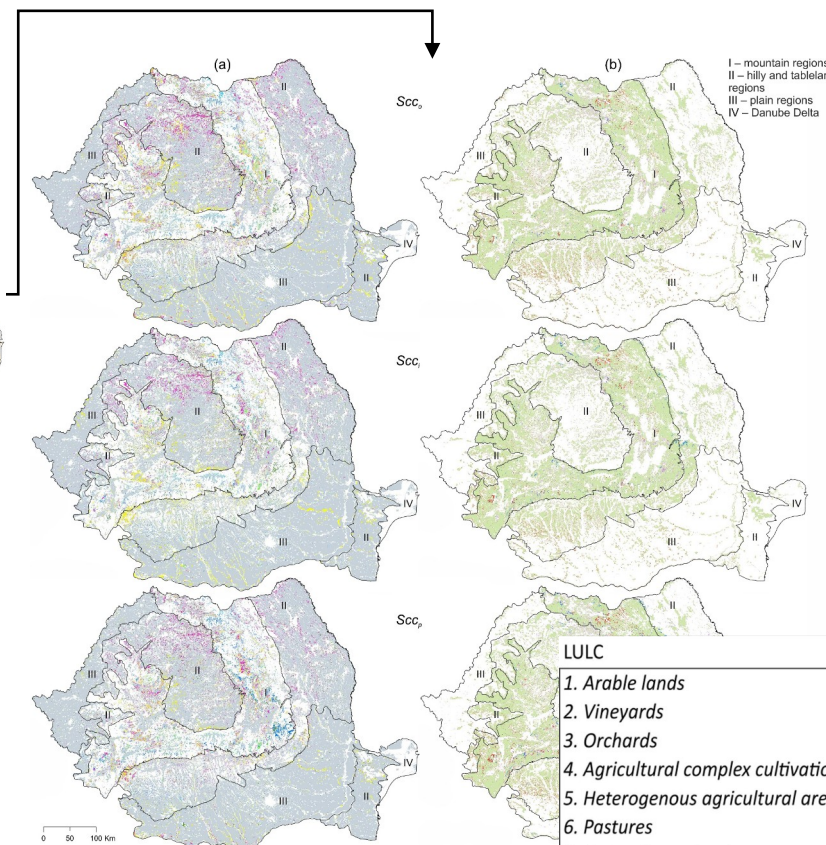
Baseline scenario (BS = reference)

SSP1-2.6

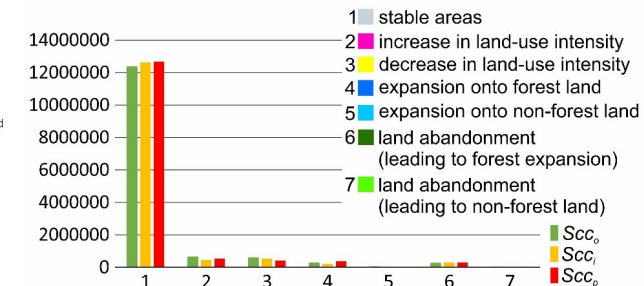


SSP3-7.0

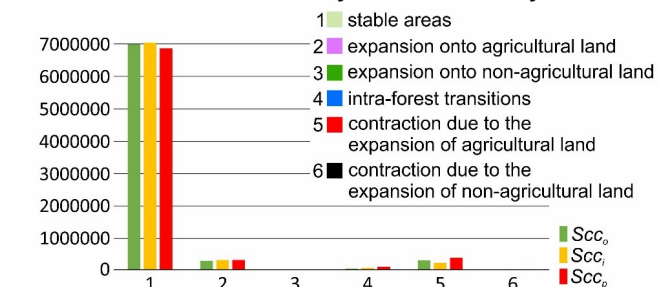
SSP5-8.5



LULC flows related to agriculture



LULC flows related to forests



LULC	CLC 2018	S_b	S_{cc0}	S_{cc1}	S_{ccp}
1. Arable lands	8,655,431	8,938,575	9,057,931	8,952,656	9,024,369
2. Vineyards	224,325	150,394	138,313	140,644	159,500
3. Orchards	278,588	175,313	222,563	213,894	212,113
4. Agricultural complex cultivation patterns	835,338	821,431	796,100	799,588	774,344
5. Heterogenous agricultural areas	917,063	692,850	665,350	678,269	642,488
6. Pastures	2,624,181	2,581,125	2,565,969	2,519,069	2,621,356
7. Natural grasslands	578,294	630,381	593,638	563,356	602,700
8. Broad-leaved forest	4,895,331	5,020,600	5,023,369	5,121,769	5,016,956
9. Mixed forest	1,043,813	1,054,513	1,050,994	1,055,794	998,981
10. Coniferous forests	1,189,244	1,217,575	1,203,275	1,201,650	1,202,544

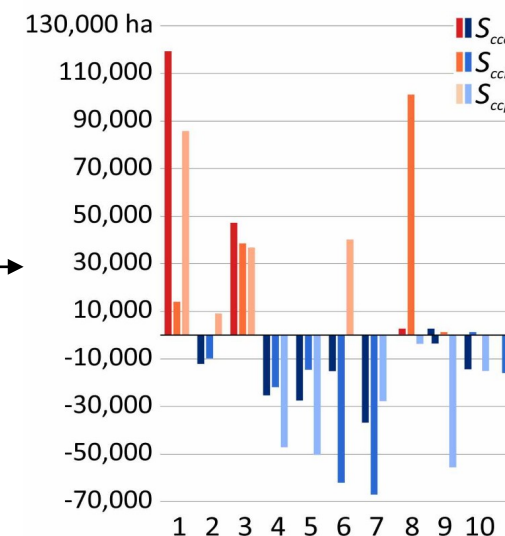
decrease increase



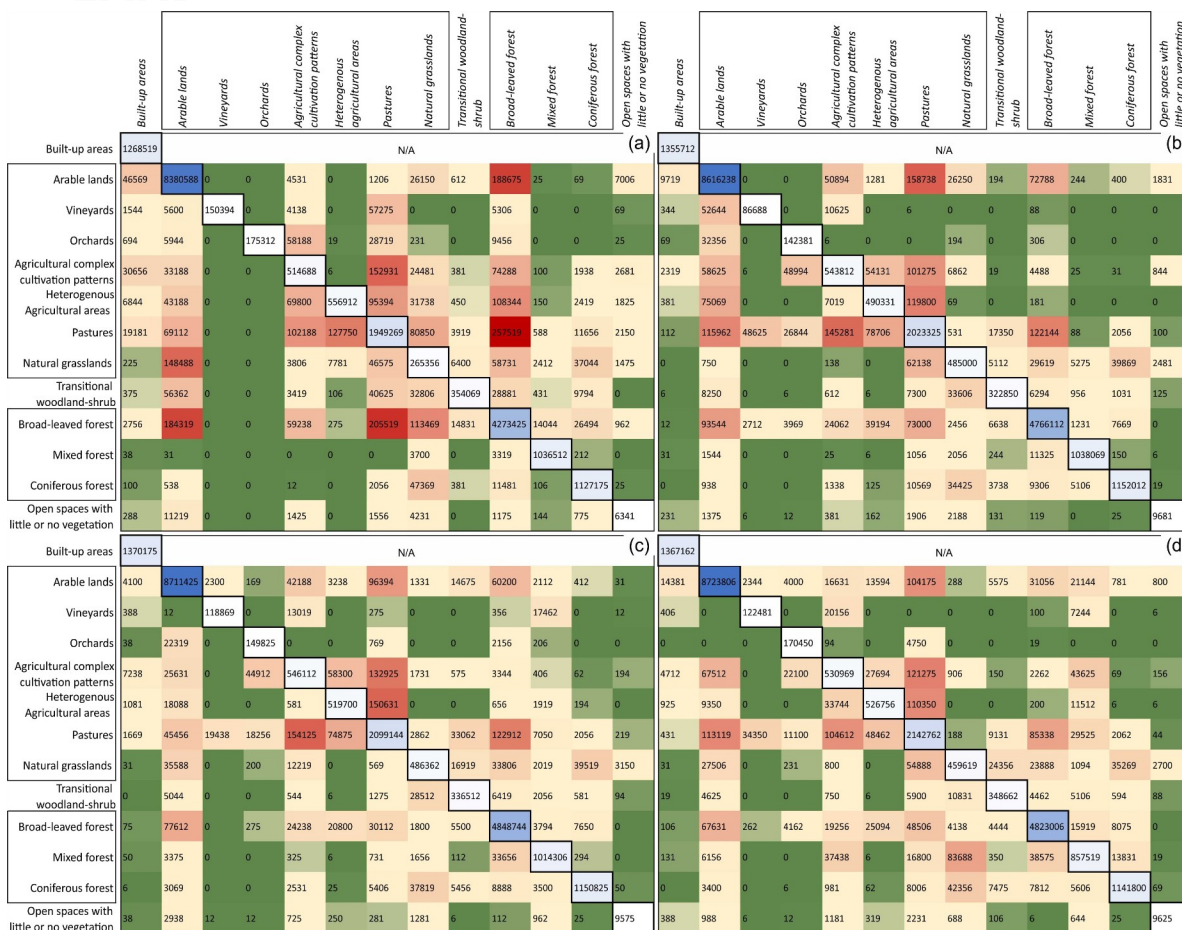
CCSs vs
BS

Results

Projected LULC transitions



Gains vs. losses



LULC transition matrices:

- (a) = BS relative to 2018
- (b) = SSP1–2.6 relative to BS
- (c) = SSP3–7.0 relative to BS
- (d) = SSP5–8.5 relative to BS

Persistence = dominant across all scenarios

Changes

- internal agricultural transitions (i.e., increases and decreases in land-use intensity) dominate across all scenario
- forest expansion over agricultural lands dominate across all scenario
- forest losses to agricultural uses

Results

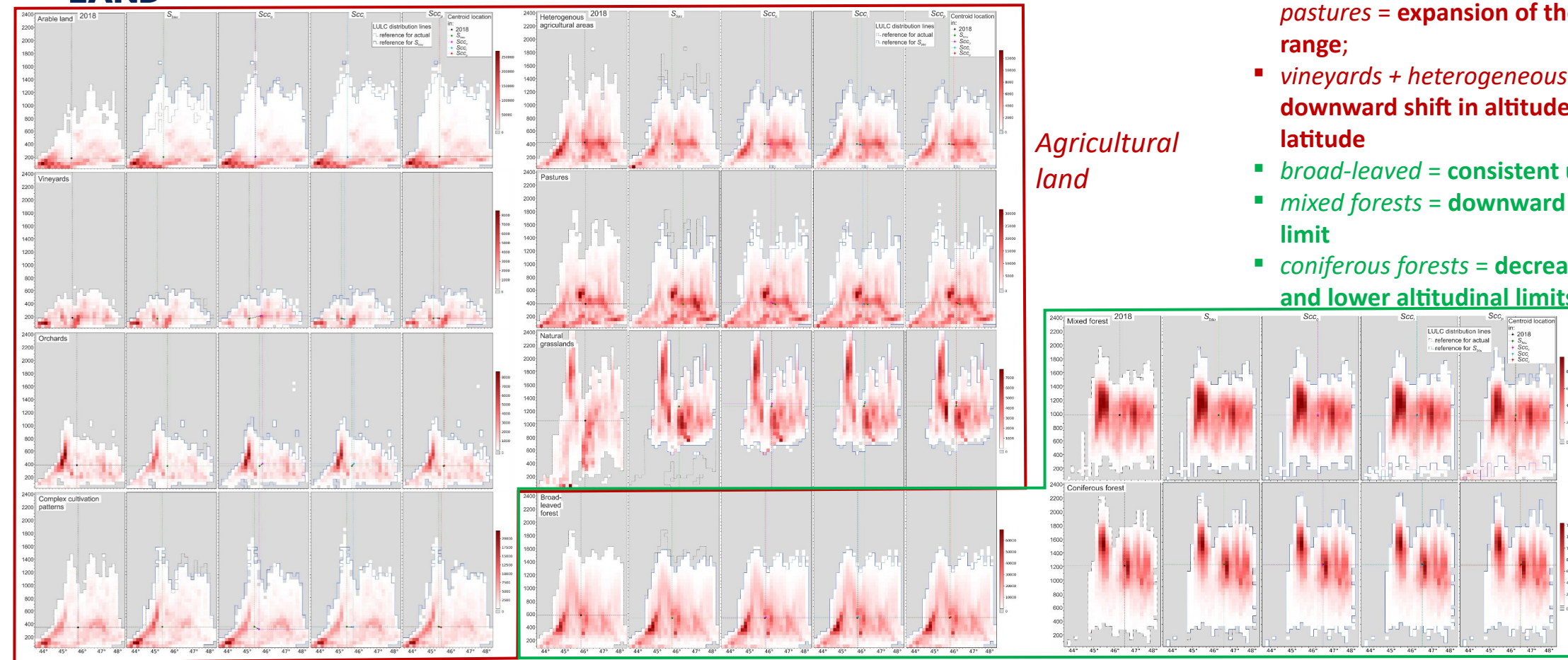
Projected altitudinal/latitudinal shifts



Agricultural land

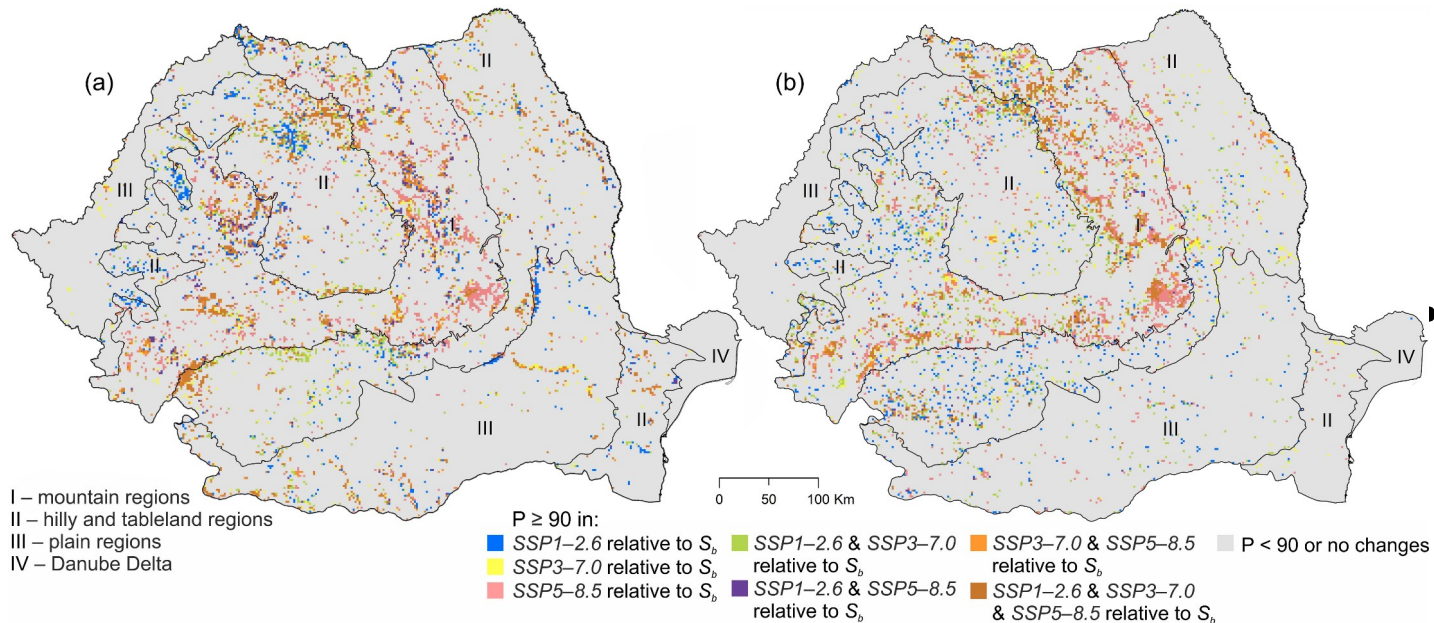
- Arable land + complex cultivation patterns + pastures = **expansion of their altitudinal range;**
- vineyards + heterogeneous agricultural areas = **downward shift in altitude & upward shift in latitude**
- broad-leaved = **consistent upward shift**
- mixed forests = **downward shift of the lower limit**
- coniferous forests = **decrease of both upper and lower altitudinal limits**

Forests



Results

Projected concentration of LULC pattern change



Spatial significant concentration of LULC changes across the scenarios



The hotspots are associated with:

- **Increase in temperature**, with a mean rise of about 0.3 °C (in SSP1-2.6) and 1.35 °C (in SSP3-7.0) to around 1.8–2.0 °C (in SSP5-8.5)

Under SSP1-2.6:

- agricultural internal dynamics: increasing land-use intensity (transitions from lower- to higher-intensity uses) & decreasing intensity (transitions from higher- to lower-intensity uses)
- internal forest transitions and gains linked to agricultural lands

Under SSP3-7.0:

- more pronounced internal and external agricultural transitions, predominantly associated with decreasing land-use intensity and forest gains
- forest land is mainly characterized by internal transitions

Under SSP5-8.5:

- dominance of external agricultural transitions linked to decreasing land-use intensity
- forest land exhibits external transitions associated with agricultural land use gains

- **decrease in precipitation** of about –5 mm (in SSP1-2.6) and –35...–40 mm (in SSP3-7.0) to approximately –55...–60 mm (in SSP5-8.5)

Summary of the main findings



➤ (To our knowledge) **this modelling is the first at national level in Romania that quantifies the potential impact of future climate change on agricultural and forest sectors**

➤ **An overall high persistence of the transitions in analysed LULC categories**

➤ **Increase in land-use intensity**, particularly in the northern part of the country
 ➤ **Decrease in land-use intensity and land abandonment** in the southern regions
 ➤ **Positive altitudinal shift for broad-leaved forests** and **expansion to lower altitudes for mixed forests**

➤ **Distinct responses of agricultural and forest sectors** to changing climatic conditions

➤ **Hilly and mainly mountain regions are more exposed** to LULC changes under climate change

➤ When comparing CCSs to BS we found that **Climate-only perturbations produced smaller changes** than current conditions

Several studies addressed to LULC modeling at national scale, but without including climate projections (e.g., [Malek et al., 2015](#); [Kucsicsa et al., 2019](#), [Kucsicsa et al., 2022](#)).

suggests a general stability of agricultural and forestry systems up to 2050 under climate change

suggest a redistribution of suitable climatic conditions, creating opportunities for expansion and relocation, as well as contractions

suggests that agricultural land exhibits a greater spatial extent of change compared to forest systems (lower ecological inertia)

suggests that high altitudes are more sensitive to climate change

suggests that anthropogenic pressures may play a more significant role in shaping LULC dynamics than projected climate changes (up to 2050)

Summary of the main findings

Policy implications



1. Overall persistence of forest and agricultural land use classes, but with significant heterogeneity at the spatial level

In general, LULC classes remain largely stable through 2050, but this masks pronounced regional variation—some areas see substantial transitions while others change little. Mountain regions stand out as particularly climate-sensitive hotspots.

- *Regionally differentiated policy: land management and adaptation strategies need to be tailored to local/regional conditions rather than applied uniformly at the national level.*

2. Agricultural systems are shifting north and upslope

There's a latitudinal shift of agricultural intensity toward the north (and a smaller upward shift in elevation), while southern regions show **declining land-use intensity** and **land abandonment** — consistent with worsening climatic suitability there.

3. Agricultural land abandonment may facilitate spontaneous reforestation/rewilding, but not necessarily biodiversity recovery.

Prolonged abandonment may also lead to the loss of open-habitat species associated with traditionally managed agricultural landscapes (e.g. pastures' biodiversity). Biodiversity outcomes therefore depend strongly on the ecological value and management history of the abandoned land.

- *Policies to tackle land abandonment in the marginal and southern agricultural areas: either to support continued viable agriculture where feasible, or to proactively plan for land-use conversion (afforestation, conservation) where abandonment is likely anyway.*

Summary of the main findings

Policy implications



4. Forests are also shifting, but more slowly. Forests show a northward latitudinal shift too, with differentiated altitudinal responses by type: broad-leaved forests moving upslope, mixed forests expanding downslope, and coniferous forests relatively stable. Forests change far less than agricultural land overall, likely due to long life cycles and high ecological inertia — they act as a buffer against short-term climatic variability.

- *Forest policy should anticipate delayed but accelerating change.*

5. Change is threshold-driven, not linear. Responses don't scale proportionally with scenario severity, suggesting ecological/land-use systems react at certain thresholds rather than gradually — making outcomes harder to predict from climate trends alone.

- *Monitoring systems and early-warning indicators may be more useful than linear projections for anticipating tipping points in specific regions.*

6. Human/institutional drivers may have a stronger influence than climate factors. Notably, climate-only scenarios produced smaller changes than baseline scenarios that include socio-economic factors — implying land management policy, market forces, and declining interest in farming may drive land-use change more than temperature/precipitation shifts alone, especially in agriculture.

- *Address non-climatic drivers directly: interventions targeting subsidies, land tenure, market incentives, and rural depopulation may be more impactful than climate adaptation measures alone.*

Thank you for your attention

Dissemination

The findings presented here are currently being considered for publication in *Scientific Reports* (Nature Portfolio).

Manuscript title: *Integrating climate change into pattern-based modelling of agricultural and forest land dynamics in Romania*

Authors: Gheorghe Kucsicsa, Mihaela Sima, Marius-Victor Bîrsan, Elena-Ana Urşanu, Dan Bălteanu